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RECORD OF REVISIONS

Rev	Date	Description	POC	OIC
0	06/28/99	Rewritten and reformatted to support LIR 220-03-01. Superseded Facilities Engineering Standards, Volume 7, Electrical, Manual Rev 15, 6/26/98.	David W. Powell, *PM-2*	Dennis McLain, *FWO-FE*
1	11/18/02	General revision and addition of endnotes. Replaces Subsections: 212, 246.6, 261, 262, and 263.	David W. Powell, *FWO-SEM*	Kurt A. Beckman, *FWO-SEM*
2	10/27/06	Updated references to codes and standards; added requirement for NRTL listing of low-voltage engine-generator systems (EGS); added reliability and maintainability requirements for EGS; added alternative for air starting system for EGS 1000 kW and larger; added requirement to use #2 diesel fuel instead of biodiesel for Level 1 EGS; added EGS system survivability requirements; added correlation between EGS/UPS "Class" and NEC Articles 700, 701, and 702; added requirement for UPS selection based on load profile; added UPS system survivability requirements; added NFPA 70E as a design requirement for battery rooms and enclosures; added battery power system survivability requirements; added personnel lightning protection for open shelters. Organization and contract reference updates from LANS transition. ISD number changes based on new Conduct of Engineering IMP 341. Master Spec number/title updates. Other administrative changes.	David W. Powell, *ENG-DECS*	Kirk Christensen, *CENG-OFF*

D5090 OTHER ELECTRICAL SYSTEMS

1.0 GENERAL

Requirements and guidance in LANL Engineering Standards Manual (ESM) Introduction, Chapter 1 Section Z10, and Chapter 7 Section D5000 apply to this Section.

2.0 ENGINE-GENERATOR SYSTEMS

2.1 General

A. Design (including addressing furnishing, installation, and acceptance testing) of engine-generator systems (EGS) using the latest editions of the following codes, standards and this Section:

1. EGSA 101P, *Engine Generator Sets Performance Standard*.[1]
2. EGSA 100B, *Engine Cranking Batteries Used with Engine Generator Sets.*
3. EGSA 100C, *Performance Standard for Battery Chargers for Engine Starting Batteries and Control Batteries (Constant Potential Static Type)*.
4. EGSA 100M, *Performance Standard for Multiple Engine Generator Set Control Systems*
5. IEEE Std 446, *IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications.*
6. NFPA 70, *National Electrical Code* (NEC).
7. NFPA 110, *Standard for Emergency and Standby Power Systems.*
8. NFPA 37, *Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines.*
9. UL 2200, *Standard for Stationary Engine Generator Assemblies* (only applicable to low-voltage EGS).
10. 40 CFR 60, *Standards of Performances for New Stationary Sources*.

B. Refer to Section D5000 paragraph 12.0 for additional requirements applicable to EGS classified as ML-1, ML-2, Safety Class, or Safety Significant.

C. Refer to LANL Master Specification Section 26 3213 *Engine Generators* [being developed] for material and installation requirements.

2.2 Minimum Rating

A. Design EGS that is capable of supplying all of the connected loads simultaneously, starting connected motor loads, and providing not less than 20 percent future load growth at an altitude of 7500 feet and an ambient temperature of 100 F.[2]

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1 The Electrical Generating Systems Association (EGSA) is a trade association made up of nearly 600 companies in the USA and around the world that make, sell, distribute, specify, service, and use on-site power equipment. The organization develops performance standards for on-site power technology.

2 Based on daily extremes for White Rock: http://weather.lanl.gov/html/WRExtremes.html

B. EGS rated 600 volts or less shall be NRTL listed to UL 2200.

C. Select EGS so the two-cycle voltage dip will not exceed 25 percent[3] during the worst case motor starting scenario.

Table D5090-1: EGS Classifications

Load	NFPA 110 Type[4]	NFPA 110 Class[5]	NFPA 110 Level[6]	NEC Article[7]
Life Safety System	10*	96[8]	1	700
Safety Class System	10*	96[8]	1	700
Safety Significant System	10*	96[8]	1	700
Security System	10*	24[9]	2	701
Critical Telecommunications System	10*	24	2	701
Other Systems	60	8	2	702

* Some systems may require uninterrupted power at the utilization equipment. In those cases the NFPA Type is the maximum time the UPS is without acceptable input power. Refer to the UPS Systems heading in Section D5090.

D. If EGS is used to back-up UPS loads exceeding 25 percent of the EGS nameplate rating it must include an isochronous governor and an UPS compatible voltage regulator. EGS must be capable of simultaneously supporting the UPS load, UPS battery charging, and UPS room cooling[10]. *Coordinate EGS selection with UPS and EGS manufacturers.*

E. If EGS will be alternate supply to adjustable speed drive or similar harmonic-generating loads exceeding 25 percent of the EGS nameplate rating, assure that the non-linear loads can

3 Voltage dip is based on the 25% drop out voltage for NEMA AC control relays.
4 Type is maximum time (in seconds) that the load is permitted to be without acceptable power. Refer to NFPA 110 (2005 Edition) §4.3 and Table 4.1(b).
5 Class is the minimum hours of operation at full load without being refueled. Refer to NFPA 110 (2005 Edition) §4.2 and Table 4.1(a).
6 Level indicates the stringency of requirements for installation, performance, and maintenance. Level is assigned to the various kinds of loads on a graded approach based on consequence of failure. Refer to NFPA 110 (2005 Edition) §4.4.
7 NEC Article 700 addresses “emergency systems.” NEC Article 701 addresses “legally required standby systems.” NEC Article 702 addresses “optional standby systems.”
8 Refer to NFPA 110 (2005 Edition) §5.1.2. Required 96 hours on-site fuel supply for Level I systems is due to the ASCE 7 seismic design category D assigned to LANL.
9 DOE M5632.1C-1 requires not less than 8 hours of standby capability power for security systems. This requirement is expanded to 48 hours due to the remoteness of LANL. Telecommunications systems are considered to be an integral part of “defense in depth” security systems and are important to public safety.
10 Refer to IEEE Std 1100-1999, paragraph 8.3.4.1.

operate successfully when powered by the EGS[11]. Coordinate with EGS and drive manufacturers to select cost-effective solution. *Possible solutions include:*

1. *Provide EGS with an isochronous governor and voltage regulator suitable for high-harmonic loads.*
2. *Provide drives with input input filters to reduce current harmonic distortion.*

F. If EGS will be alternate supply to elevators loads exceeding 25 percent of the EGS nameplate rating, assure that elevator controller has provisions to absorb regenerative power[12]. *Coordinate EGS selection with elevator and EGS manufacturers.*

G. Design EGS of the NFPA 110 type, class, and level to meet the User's operational needs for emergency or standby power and to meet the requirements in Table D5090-1. Design EGS and associated distribution system to meet the NEC Article indicated in Table D5090-1.

H. Specify engines that will meet "new source performance standards" required by 40 CFR 60.

2.3 Reliability/Maintainability

A. Locate Level 2 EGS with nameplate rating greater than 400 kW[13] and all Level 1 EGS in a dedicated generator room designed to protect the EGS and accessories from wind driven debris and other natural phenomena hazards in accordance with DOE-STD-1020.[14]

1. Provide space heating for reliable starting and adequate cooling while EGS is operating.[15]
2. Provide adequate space, access pathways, and other provisions necessary for safe and efficient maintenance, repair, and replacement of the EGS.[16]
3. Refer to Chapter 7 of NFPA 110 for additional requirements.

B. For Level 1 EGS with required capacity at 7500 ft. greater than or equal to 1000 kW[17] use an N+1 redundant parallel configuration of engine-generators, where N is the number of engine-generators required to serve the load.[18]

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11 Refer to IEEE Std 446-1995, paragraph 6.4.2.3. In addition to concerns about effects of harmonics on engine-generator performance, concerns also exist about interactions between adjustable speed drives served by relatively high impedance sources such as engine-generators.

12 Refer to NEC Section 620.91.

13 400 kW is about the upper limit for standard commercial sound-attenuating weather-protective housings for engine-generators.

14 Refer to Chapter 3 of DOE-STD-1020-2002.

15 Refer to NFPA 110 (2005 Edition) §5.3.

16 Refer to NFPA 110 (2005 Edition) §7.2.5 and §7.7.

17 Engine generator set cost per kW is at a minimum in the 300 kW to 600 kW range, then increases 2X for 1000 kW sets and 2.5X for 2000 kW sets. Factoring in the added costs for paralleling switchgear indicates favorable costs for parallel EGS systems starting at 1000 kW with the required capacity made up of 300 to 600 kW sets.

18 Refer to IEEE Std 446 §4.2.6 and EGSA 100M §6.1; benefits of parallel-redundant EGS include: **Reliability** — Reliability is inherently greater with multiple generator sets. A faulty unit can be serviced or repaired while others maintain power; **Economy** — Several smaller units may cost less than one larger unit. Smaller units are easier to ship and install at the job site. Smaller units may be run or shut down as a function of load demand to increase engine life and to maintain high fuel efficiency; **Modular design** — Modular commonality of equipment with a lower cost structure and ease of upgrade to add additional units; **Ease of installation** — The ability to lift, move, and place the smaller engine-generators with conventional forklift trucks instead of heavy cranes; **Availability** — Delivery within normal lead times, unlike competing large units that are frequently backlogged; **Reduced maintenance costs** — Serviceable by diesel technicians at lower hourly rates, unlike

1. Determine the required number of engine-generator sets using procedures described in UFC 3-540-04N (MIL-HDBK-1003/11), *Diesel-Electric Generating Plants*.
2. *An N+1 configuration will allow for maintenance or repair of an engine-generator while the EGS system continues to support the critical load.*
3. Provide each engine-generator with an isochronous load sharing type governor.[19]
4. Provide each engine-generator with a regulator equipped for paralleling and connected for compensation by either the droop or the differential (cross current) method.[20]
5. Provide each engine-generator with a dedicated fuel supply system that includes pumps, piping, and day tank. *A common bulk fuel storage system may be used to the extent permitted by NFPA 110.*
6. Provide automatic random access paralleling controls that use electrically-operated low-voltage power circuit breaker switchgear and control power from a stationary battery system or UPS system.[21]

C. For Level 1 EGS with required capacity at 7500 ft. of less than 1000 kW, use an N+1 parallel redundant configuration as described above, or provide a location for and means to safely connect a temporary engine-generator system whenever the permanent generator is out of service for major maintenance or repair.[22]

1. The means to connect the temporary engine-generator system must be such that:
   - No hazardous voltage will be present in the permanent generator or its control or protective devices when the temporary engine-generator system is operating, and no hazardous voltage will be present in the temporary engine-generator system or its control or protective devices when the permanent EGS is operating[23], and
   - There is overcurrent protection for conductors and the temporary engine-generator system as required by the NEC[24].
2. The location for the temporary engine-generator system must be:
   - Designated and marked for the purpose,
   - Accessible for placing a trailer-mounted or portable unit of suitable size, and
   - Protective against natural phenomena hazards (e.g. wind-driven debris).

D. Specify water jacket heater(s) for each EGS installation.[25]

E. Specify battery heater(s) for each outdoor installation and as recommended by EGS manufacturer for indoor installations.

larger single engine units requiring more specialized and costly service; **Less expensive parts** — Replacement and maintenance parts less expensive and more commonly available than for larger single engine units.

19 Refer to EGSA 100M §6.2.1.
20 Refer to EGSA 100M §6.2.2.
21 Refer to EGSA 100M §6.2.6.
22 Refer to NEC Section 700.5(B). This NEC requirement for emergency systems applies to Level 1 systems.
23 Refer to NEC Section 445.18.
24 Refer to NEC Section 445.12.
25 Refer to §5.3.1 in NFPA 110 (2005 Edition).

2.4 Energy Source[26]

A. Base EGS energy source (fuel) type selection on the following requirements and guidance:

1. Level 1 system: No. 2 Diesel fuel.[27, 28]
2. *Level 2 system: No. 2 Diesel fuel or natural gas.*

B. Design fuel system with adequate capacity to meet the NFPA 110 Class requirements plus capacity for required acceptance testing, periodic exercising, and testing.

C. Design fuel systems that meet the requirements of NFPA 37. Meet specific requirements in the following codes as applicable:

1. NFPA 54, *National Fuel Gas Code*.
2. NFPA 30, *Flammable and Combustible Liquids Code*.

D. Use NRTL listed tanks and suitable secondary containment for liquid fuel systems as follows:

1. Single-wall steel tanks installed in aboveground or underground concrete containment structures or vaults that also facilitate visual inspection for tank leaks. Tanks must meet applicable requirements in UL 142, *Standard for Steel Aboveground Tanks for Flammable and Combustible Liquids.*
2. Aboveground, double-wall, steel tanks with supplemental mechanical and fire protection and suitable leak detection systems. Tanks must meet applicable requirements in UL 142; supplemental mechanical and fire protection must meet applicable requirements in UL 2085 *Standard for Protected Aboveground Tanks for Flammable and Combustible Liquids.*

2.5 Transfer Switch

A. Use one or more NRTL-listed transfer switches to transfer emergency and/or standby loads from the normal power source to an alternate power source.[29]

1. Use automatic transfer switch(es) for Level 1 loads.[30]
2. Use automatic transfer switch(es) for Level 2 loads where the system must meet NEC Article 701.[31]
3. Use automatic or manual transfer switch(es) for Level 2 loads where the system is to meet NEC Article 702.[32]

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26 Refer to NFPA 110 (2005 Edition) §5.1.

27 On-site fuel supply is required because the probability of interruption of off-site fuel supply is considered high due to remoteness of LANL and the possibility of seismic activity.

28 Biodiesel B5, B20, or B100 blends should not be used with EGS because of the limited experience with biodiesel fuels in EGS service and concerns about the stability of this material during the long-term fuel storage typical of EGS. Refer to *Assessing Biodiesel in Standby Generators for the Olympic Peninsula*, Final Report, Prepared for the Bonneville Power Administration, July 2004. This document indicates good success with biodiesel in transportation equipment, but results ranging from success to failure in standby generator systems.

29 Refer to NFPA 110 (2005 Edition) Chapter 6 and IEEE Std 446 paragraph 6.3.

30 Refer to NEC Section 700.6.

31 Refer to NEC Section 701.7.

32 Refer to NEC Section 702.6.

B. In addition to the requirements of the NEC and NFPA 110[33], specify the following for automatic transfer switches:

1. Bypass-isolation type transfer switches for all permanent installations.[34]
2. Time delay on start of engine-generator: 1 second.[35]
3. Time delay on transfer to EPS: 0 to 5 seconds, initially set at 1 second.[36]
4. Time delay on retransfer to normal source: 30 minutes.[37]
5. Transfer switch operations counter.[38]
6. In-phase monitor for motor loads.[39]
7. 4-pole transfer switch for 3-phase, 4-wire systems with same the voltage as the building service.[40]

C. Use transfer switches that are NRTL listed to UL 1008 – *Standard for Safety for Transfer Switch Equipment* and are selected and protected according to the short circuit and over-voltage considerations outlined in IEEE Std 446.[41]

2.6 Starting System

A. For engine-generator sets smaller than 1000 kW specify starting battery system as required by NFPA 110 and the following:

1. Lead-acid type battery,[42] which meets EGSA 100B.
2. Automatic battery charger, with equalize charge timer, that meets EGSA 100C.

B. For engine-generator sets with nameplate rating of 1000 kW and larger specify either starting battery system as described above or a dedicated compressed air starting as described below. Consult with engine-generator manufacturer to determine which alternative best meets the particular operational requirements of the system.

1. Design air starting system sized for not less than 3 cranking cycles per engine.[43]
2. Provide two starting-air compressor units, one unit with an electric-motor drive, and one unit with a dual electric-motor/diesel-engine drive with battery start for the engine drive. Power electric compressor motors from the EGS.

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[33] Refer to NFPA 110 (2005 Edition) Chapter 6.
[34] A bypass-isolation transfer switch permits safe maintenance of the transfer switch while keeping critical systems in operation: refer to §4.3.10 in IEEE Std 446-1995.
[35] Refer to A.6.2.5 in NFPA 110 (2005 Edition).
[36] Refer to 6.2.7 in NFPA 110 (2005 Edition).
[37] Refer to A.6.2.8 in NFPA 110 (2005 Edition).
[38] Refer to A.6.2.13 in NFPA 110 (2005 Edition).
[39] In-phase transfer systems permit motors to continue to run with little disturbance to the electrical system and processes during re-transfer operation; refer to §4.3.8 in IEEE Std 446-1995.
[40] Engine-generator systems usually have a factory-made connection from the generator neutral to the frame of the machine. The purpose of the 4-pole transfer switch is compliance with 2005 NEC section 250.24(A)(5) which prohibits load side grounding connections to the grounded (neutral) conductor.
[41] Refer to Chapter 6 in IEEE Std 446-1995.
[42] The hazardous waste issues associated with nickel-cadmium batteries preclude their use; refer to §5.3.2 in IEEE Std 446-1995.
[43] Refer to UFC 3-540-04N (MIL-HDBK-1003/11).

3. Manifold compressed air receivers in parallel, each with safety valves, isolating and flow check valves, and automatic condensate drain trap assemblies. For normal operating each engine shall have its own starting air tank so that unsuccessful start of a specific engine does not deplete the available compressed air. Under emergency conditions, the manifold shall allow for alternate supply from other tanks to the engines.
4. Receiver construction shall conform to American Society of Mechanical Engineers (ASME) SEC 8D, *Pressure Vessels*, for the system pressures involved.
5. Use components of the compressed air starting system for no other purpose than engine-generator starting.

2.7 Remote Annunciation

A. For Level 1 systems design the NFPA 110 required remote common alarm of engine generator malfunction[44] at the following locations:

1. At a location in the facility that is outside the generator room and is observable.[45]
2. A location that is continuously staffed; *this may be in another building that has control over the system or at a central monitoring facility*.

B. For Level 2 systems design the NFPA 110 required remote common alarm of engine generator malfunction at a location in the facility that is outside the generator room and observable by personnel.

2.8 Noise and Vibration Control

A. Design suitable noise and vibration isolation systems for EGS installed inside or outside of buildings. The location of the EGS and the uses facilities and spaces adjacent to the EGS will influence the type and degree of noise and vibration isolation required.

B. Use the following noise control systems as appropriate to limit EGS air-borne noise to a maximum of 70 dB(A) measured at ground level exterior locations 50 feet in any direction from the center of the generator set[46]:

1. Critical type muffler(s) providing 25 to 35-dB attenuation in the 125 to 1000 Hz range.
2. Exhaust discharge pointed up.
3. Sound deflecting barrier in front of radiator discharge opening.[47]
4. Sound-attenuating louvers on air-intake opening(s) into generator room.
5. Intake silencer for turbo-charged engines; *may be combined with air cleaner*.
6. Sound attenuating housings and/or sound barriers for outdoor installations.[48]

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44 Refer to §5.6.5.2(4) in NFPA 110 (2005 Edition).
45 Refer to §5.6.6 in NFPA 110 (2005 Edition).
46 Refer to *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety*, dated March 1974, prepared by the U.S. Environmental Protection Agency Office of Noise Abatement and Control.
47 The radiator fan is a significant source of engine-generator set noise.
48 Generator sets may be enclosed in commercially available weather-protective sound attenuating housings that reduce noise to less than 70 dBA measured 15 meters away.

C. Design suitable noise and vibration isolation systems to limit EGS noise in nearby occupied rooms, spaces, or facilities as follows:

1. Industrial occupancies: Less than 10 dB(A) increase above ambient noise level when the EGS is operating at full load.
2. Office or laboratory occupancies: Less than 5 dB(A) increase above ambient noise level when the EGS is operating at full load.

D. *Consult with the EGS manufacturer, vibration isolation system manufacturers, or an acoustical engineer to determine suitable noise and vibration isolation systems.*

2.9 EGS System Survivability

A. Level 1 EGS systems have an I_p of 1.5 and must be capable of performing their intended function during and after a design basis seismic event.[49]

B. Equipment for EGS systems designated with I_p greater than 1.0 must be certified by the manufacturer to withstand the total lateral seismic force and seismic relative displacements specified in the IBC or ASCE 7.

1. Component manufacturer's certification shall be based on shake table testing or experience data (ie, historical data demonstrating acceptable seismic performance), or by more rigorous analysis providing for equivalent safety.
2. Required response spectra shall exceed 1.1 times the in-structure spectra determined in accordance with IBC AC156 *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems*.

C. Design support and seismic anchorage for EGS system components and associated auxiliary equipment in accordance with ESM Chapter 5 and the more stringent requirements of NFPA 110 (including appendices[50]), IBC, or ASCE 7.

D. Refer to LANL Master Specification Section 26 0529, *Hangers and Supports for Electrical Systems* for material and installation requirements.

E. Do not locate EGS system in a building basement that is subject to flooding.[51] Consider the following flooding events:

1. Water from fire fighting,
2. Pipe breaks that require 2 hours to shut down,
3. Water from a 100-year natural phenomena event.

F. Separate EGS and EGS equipment (e.g. conductors, disconnecting means, overcurrent protective devices, transfer switches, and all control, supervisory, and support devices up to and including the branch circuit panelboards) from normal power service and/or system equipment as follows[52]:

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[49] Refer to §7.11.6 in NFPA 110 (2005 Edition). LANL is ASCE 7 seismic category D.
[50] Recommendations in A7.11.5 in NFPA 110 made requirements at LANL.
[51] Refer to NFPA 110 (2005 Edition) §7.2.3
[52] Refer to §7.2.2 and Annex A §A7.2.2 in NFPA 110 (2005 Edition). Appropriate consideration has given to providing adequate fire and arc-blast protection to EGS equipment so a single event will not disable both the normal and emergency or standby power systems.

1. Level 1 EGS or EGS equipment shall not be installed in the same room with the normal service equipment. *Refer to paragraph 2.2 in Section D5010 for definition of service point.*
2. Level 1 EGS or EGS equipment shall not be installed in the same room with the normal power system equipment rated over 150 volts to ground and equal to or greater than 1000 amperes.
3. Level 2 EGS or EGS equipment shall not be installed in the same room with the normal service equipment rated over 150 volts to ground and equal to or greater than 1000 amperes.

2.10 Load Testing Provisions

A. For a Level 1 or Level 2 EGS, specify means to monthly exercise the system under not less than 30 percent of nameplate kW rating or greater percentage if recommended by the engine-generator manufacturer.[53]

B. Design a permanently installed[54] load bank for a Level 1 or Level 2 EGS under either of the following circumstances:

1. The steady-state kW of the facility load connected to the EGS is less than 30% of the EGS nameplate kW rating.
2. The User is reluctant to use the facility load for the NFPA 110 required monthly exercising of the EGS.
3. Design system to automatically replace the load bank with the emergency or standby loads in case of failure of the primary source during load testing.[55]

C. *Large systems that are designed to operate in parallel with the utility system may use the utility system as the load for testing and monthly exercising.*

2.11 Generator Output

A. Design an accessible circuit breaker in the generator output circuit; locate circuit breaker either on the EGS or at a location in sight from the EGS and within 25 ft circuit distance from the generator output terminals.[56]

B. Circuit breaker shall be the NEC required disconnecting means for the generator.[57]

C. Circuit breaker shall provide overcurrent protection for the generator and the output conductors.[58]

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[53] Refer to §8.4.2 in NFPA 110 (2005 Edition).

[54] Refer to §8.4 in NFPA 110 (2005 Edition). The EGS must be exercised at least monthly under not less than 30% nameplate kW load. If the facility load connected to the EGS does not meet this requirement, or is not available for operational reasons, a supplemental load bank must be provided. It is not practical to use portable load banks for the monthly exercising of all the EGSs at LANL.

[55] Refer to §8.4.2.2 in NFPA 110 (2005 Edition).

[56] Refer to UL 2200, section 25.3. For large EGS with output rated more than 800 amperes it may be advantageous to locate the output circuit breaker in a switchgear assembly instead of on the EGS.

[57] Refer to Section 445.18 in the NEC (2005 Edition).

[58] Refer to Section 445.12 in the NEC (2005 Edition).

D. Specify ground fault detection and alarm system if the generator circuit breaker rating exceeds 1000 amperes on 480Y/277V systems.[59]

E. Design conductors from the generator terminals to the circuit breaker terminal with an ampacity not less than 115 percent of the generator nameplate rating.[60]

F. Refer to Section D5000 for overcurrent protective device selective coordination requirements.

2.12 Grounding

A. Bond the EGS frame to the main grounding electrode ground bar or to a main grounding electrode ground bar extension using IEEE 837 compression lugs and grounding electrode conductor sized per NEC Table 250.66.

B. Bond the grounded conductor to the generator frame using a main bonding jumper sized per Table 250.66.[61]

2.13 Acceptance Testing

A. Specify on-site acceptance testing of EGS as required by the NEC and NFPA 110.[62]

1. Provide advance notification of acceptance testing to the LANL Electrical AHJ.[63]
2. Tests shall be performed by qualified personnel such as the EGS manufacturer's factory-trained technicians or technicians that are certified in accordance with ANSI/NETA ETT-2000, *Standard for Certification of Electrical Testing Technicians*.
3. In addition to tests required by the NEC and NFPA 110, verify successful operation of EGS and associated equipment with connected facility loads, and successful starting and operation of all connected motor loads.
4. Require a detailed record of acceptance test results on a form suitable for the purpose.
5. Require that analysis and recommendations with the acceptance test report.

B. Specify LANL witnessed factory acceptance testing of EGS as follows:

1. A single unit EGS nameplate rated 1000 kW or more,
2. Any multiple unit EGS; factory testing of multiple unit EGS must also include the paralleling switchgear.
3. Any Safety Class or Safety Significant EGS.

C. Provide copies of the acceptance test report and all certifications required by NFPA 110 to the LANL electrical AHJ and to the Facility Manager.

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59 Refer to Section 700.7(D) in the NEC (2005 Edition). This NEC requirement for emergency systems is extended to standby systems at LANL.
60 Refer to Section 445.13 in the NEC (2005 Edition).
61 Refer to Chapter 7 in IEEE Std 446 for a discussion of the pros and cons of grounding the neutral at the generator and using 4-pole transfer switches. Problems associated with multiple transfer switches, ground fault protection of the emergency system, and potential hazardous conditions during certain maintenance operations are largely eliminated through grounding the neutral at the generator and using 4-pole transfer switches.
62 Refer to §7.13 in NFPA 110 (2005 Edition).
63 Refer to §7.13.3 in NFPA 110 (2005 Edition).

3.0 UPS SYSTEMS

3.1 General

This heading addresses permanently installed uninterruptible power supply (UPS) systems rated 1 kVA and larger. *It is anticipated that guidance will be added later addressing rack-mounted UPS equipment and plug connected commodity UPS equipment.*

3.2 UPS Selection

A. Design (including the furnishing, installation, and acceptance testing) of UPS systems to meet the User's operational needs for uninterruptible, computer-grade power in conformance to the latest edition of the following codes and standards and this Section:

1. IEEE Std 446, *IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications*
2. IEEE Std 493, *IEEE Recommended Practice for Design of Reliable Industrial and Commercial Power Systems*
3. IEEE Std 944, *IEEE Recommended Practice for the Application and Testing of Uninterruptible Power Supplies for Power Generating Stations*
4. IEEE Std 1100, *IEEE Recommended Practice for Powering and Grounding Electronic Equipment*
5. NFPA 70, *National Electrical Code* (NEC)
6. NFPA 111, *Stored Energy Emergency and Standby Power Systems*
7. IEC 62040, *Uninterruptible Power Systems*
8. NEMA PE 1, *Uninterruptible Power Systems – Specification and Performance Verification*
9. UL 1778, *Uninterruptible Power Systems – Third Edition*.

B. Refer to Section D5000 paragraph 12.0 for additional requirements applicable to UPS systems classified as ML-1, ML-2, Safety Class, or Safety Significant.

C. Design on-line, double-conversion UPS systems[64] (defined as UPS that continuously derive output alternating current power from direct current or high frequency alternating current).

D. Select static (Refer to Figure D5090-1) or rotary (Refer to Figure D5090-2) power conversion UPS equipment and UPS energy storage system (e.g. batteries, flywheel, etc.) type based on a 20-year life cycle cost analysis. *Consider the following factors as applicable:*

1. *Initial cost of UPS, energy storage system, and directly associated building floor space (e.g., UPS room, battery room) and support systems (e.g., UPS cooling, battery room ventilation, and special plumbing).*
2. *UPS energy costs including those of directly related building support systems.*

[64] A UPS system with true online double conversion provides complete isolation from problems originating from utility or generator power. Other UPS topologies may have lower initial costs, they may not provide protection against all power problems including power system short circuits, frequency variations, harmonics, and common-mode noise. Refer to §5.5.3.1 in IEEE Std 446-1995.

3. *Scheduled maintenance costs for UPS, energy storage system, and directly associated building floor space and support systems.*
4. *Predicted repair and replacement costs for UPS components, energy storage system, and directly associated building support systems.*

Figure D5090-1: Typical Static UPS System

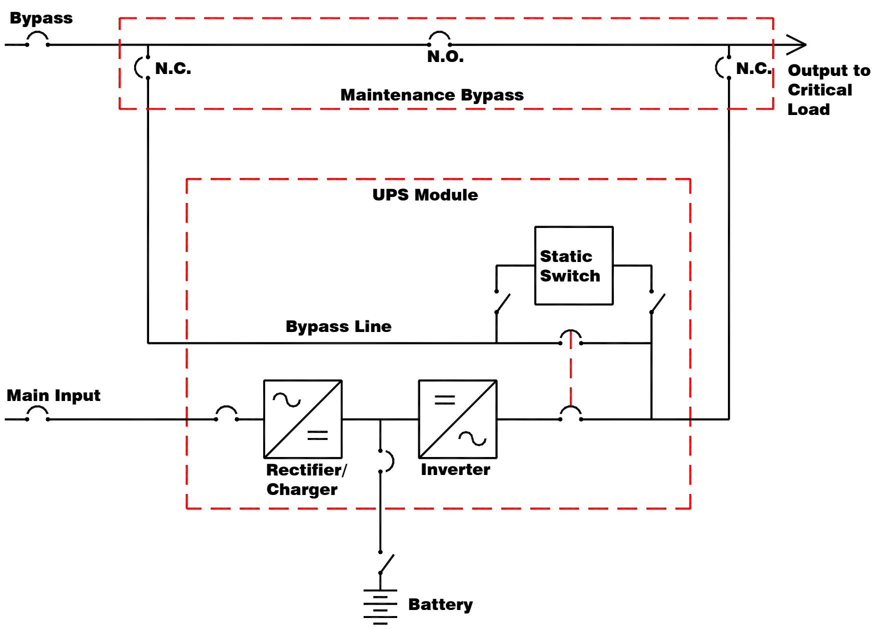
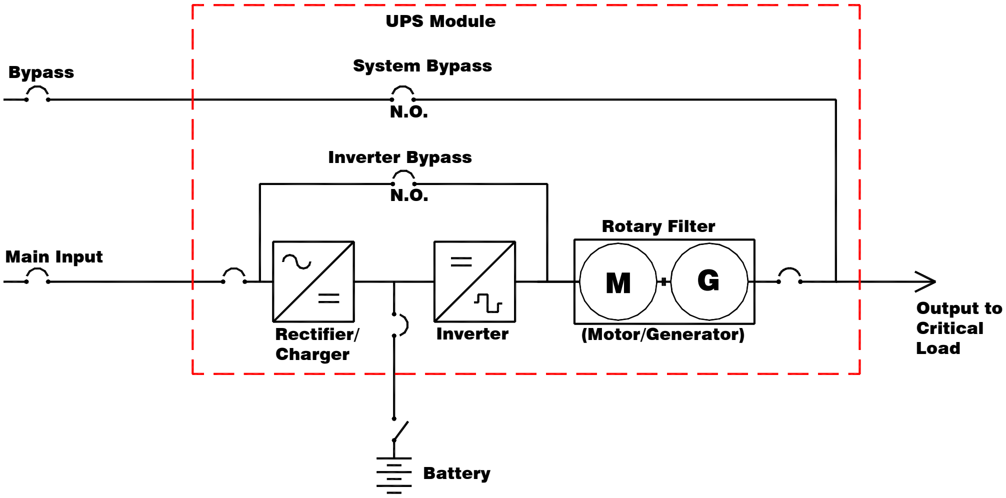


Figure D5090-2: Typical Rotary UPS System



E. Refer to LANL Master Specification Section 26 3353, *Static Uninterruptible Power Supply* for material and installation requirements for UPS rated 15 kVA and greater.

F. De-rate UPS capacity for operation at 7500-ft elevation: *verify with manufacturer*.

G. Select UPS based on a load profile that considers the following factors:

1. Type of load - Data processing equipment, main frame chilled water pump, etc.
2. Size of load - kVA or kW rating, horsepower, voltage, and amperage of load.
3. Switching pattern – Un-switched; cycled daily; cycled hourly; operated by thermostat; building management system control.
4. Transient characteristics - Specify inrush current magnitude and duration (i.e., 15 times steady state RMS current for ¼ cycle for electric discharge lighting); range of power factor variation (i.e., as low as 0.4 lagging for electric discharge lighting); voltage dip.
5. Steady-state characteristics - specify range of power factor, particularly if outside the 0.8 lagging to 1.0 range. UPS derating is normally required for the unusual circumstance of loads at leading power factor. Consult vendors if in doubt. In some cases a demand factor might be applicable to the load.
6. Special factors - Harmonic characteristics; factors that vary with temperature or age. The designer may vary the load profile format. Estimated or approximated load data may be used in the absence of exact information but should be so identified.
7. Include not less than 20 percent future load growth capacity.

H. Evaluate the UPS application to anticipate problems and to adjust the design accordingly. *The problems associated with UPS/load interaction can be reduced by:*

1. *Large Transformer Applications:*
   - *Use a transformer specifically designed for the transient specifications of the UPS.*
   - *Use a UPS with characteristics that will not cause the transformer to saturate.*
2. *Motor Applications:*
   - *Use a UPS capable of providing motor inrush without current limiting.*
   - *Transfer the load bus to an alternate source to start the motor and retransfer to the UPS after the motor has started.*
   - *Oversize the UPS so the motor load represents a small portion of the UPS capacity.*
   - *Use a UPS with an inverter filter that is compatible with synchronous motors.*
3. *Other Nonlinear Loads:*
   - *Use a UPS with a modified inverter filter.*
   - *Oversize the UPS.*
   - *Avoid connection of electric discharge lighting to the UPS. Use other emergency sources for this lighting.*

I. Provide UPS systems of the NFPA 111 type, class, and level to meet the User’s operational needs for uninterruptible, computer-grade power and the requirements in Table D5090-2. Design UPS and associated distribution system to meet requirements in the NEC Article indicated in Table D5090-2.

Table D5090-2: UPS Classifications

Load	NFPA 111 Type[65]	NFPA 111 Class[66]	NFPA 111 Level[67]	NEC Article
Safety Class System	0	0.25 plus Level 1 EGS backup*	1	700
Safety Significant System	0	1.5 without generator backup 0.25 with Level 1 EGS backup	1	700
Life Safety System	0	1.5 without generator backup 0.25 with Level 1 EGS backup	1	700
Critical Telecommunications System	0	1.5 without generator backup 0.25 with Level 2 or Level 1 EGS backup	2	701
Security System	0	8 without generator backup[68] 0.25 with Level 2 or Level 1 EGS backup	2	701
Other	0	0.25 without generator backup 0.083 with generator backup	3	702

*Provide engine-generator system (EGS) backup for systems that support Safety Class Systems.[69]

J. Use UPS manufacturers with emergency response capabilities as follows:[70]

1. Level 1 systems: 4 hours or less.
2. Level 2 systems: 8 hours or less.
3. Level 3 systems: 12 hours or less.

3.3 UPS Survivability

A. Level 1 UPS systems have an I_p of 1.5 and must be capable of performing their intended function during and after a design basis seismic event. [71]

B. Equipment for UPS systems designated with I_p greater than 1.0 must be certified by the manufacturer to withstand the total lateral seismic force and seismic relative displacements specified in the IBC or ASCE 7.

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65 Refer to §4.2.2 in NFPA 111 (2005 Edition). Type 0 characterizes UPS system with online double conversion.

66 Refer to §4.3 in NFPA 111 (2005 Edition). Class is the minimum time, in hours, for which the UPS is designed to operate at rated load without being recharged. Class is assigned to the various kinds of loads on a graded approach based on consequence of failure. NEC Sections 700.12(A) and 701.11(A) set the minimum run time at 1.5 hours for both emergency systems and legally required standby systems; NEC Section 700.12 indicates one or more type of system can be used to meet emergency or standby power requirements.

67 Refer to §4.5 in NFPA 111 (2005 Edition). Level indicates the stringency of requirements for installation, performance, and maintenance. Level is assigned to the various kinds of loads on a graded approach based on consequence of failure.

68 DOE M5632.1C-1 requires not less than 8 hours of standby capability power for security systems.

69 Refer to Figure 3 in IEEE Std. 308-2001.

70 Emergency response time is the total time it takes for a service provider to arrive on the job site after an emergency service request has been placed. Response time is based on Level using a graded approach based on consequence of failure.

71 Refer to §7.4.5 in NFPA 111 (2005 Edition). LANL is ASCE 7 seismic category D.

1. Component manufacturer's certification shall be based on shake table testing or experience data (i.e. historical data demonstrating acceptable seismic performance), or by more rigorous analysis providing for equivalent safety.
2. Required response spectra shall exceed 1.1 times the in-structure spectra determined in accordance with IBC AC156 *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems*.

C. Design support and seismic anchorage for UPS system components and associated auxiliary equipment in accordance with ESM Chapter 5 and the more stringent requirements of NFPA 111 (including appendices), IBC, or ASCE 7.

D. Do not locate UPS or associated equipment in a location subject to flooding.[72] Consider the following flooding events:

1. Water from fire fighting,
2. Pipe breaks that require 2 hours to shut down,
3. Water from a 100-year natural phenomena event.

E. Separate UPS and UPS equipment (e.g. conductors, disconnecting means, overcurrent protective devices, transfer switches, and all control, supervisory, and support devices up to and including the branch circuit panelboards) from normal power service and/or system equipment as follows[73]:

1. Level 1 UPS or UPS equipment shall not be installed in the same room with the normal service equipment.
2. Level 1 UPS or UPS equipment shall not be installed in the same room with the normal power system equipment rated over 150 volts to ground and equal to or greater than 1000 amperes.
3. Level 2 UPS or UPS equipment shall not be installed in the same room with the normal service equipment rated over 150 volts to ground and equal to or greater than 1000 amperes.

3.4 UPS Configuration

A. Select UPS system configuration using the following factors:

B. Specify bypass switches[74] based on the following requirements; refer to Figure D5090-1:

1. Provide UPS systems over 3.5 kVA with an automatic high-speed bypass switch.[75]
2. Provide three-phase UPS systems 12 kVA and over with a static bypass switch.

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72 Refer to §7.2.2 in NFPA 111 (2005 Edition).

73 Refer to §7.7.2 and Annex A §A7.7.2 in NFPA 110 (2005 Edition). Logic for protecting generator-based emergency and standby power equipment is extended to Level 1 and Level 2 UPS systems. Appropriate consideration must given to providing adequate fire and arc-blast protection to UPS equipment so a single event will not disable both the normal and emergency or standby power systems.

74 Addition of a bypass switch makes the UPS system 8 – 10 times more reliable. Refer to §5.5.4.3 in IEEE Std 446-1995.

75 Based on capabilities of commercially available products.

3. Provide an external, manually operated, make-before-break maintenance bypass switch with padlocking provisions or plug control for UPS systems 2 kVA and over. UPS module cabinet must be completely isolated and de-energized during maintenance.[76]

4. Install a separate bypass input circuit for three-phase UPS systems 12 kVA and over.[77]

C. Certain critical loads such as Safety Class systems or critical telecommunications loads may require increased system reliability beyond that which can be provided by a single-module UPS system. Determine reliability requirements and system capabilities using analysis methods described in IEEE Std 493.[78] Consider the following special configurations to increase UPS system reliability:

1. *Use two or more UPS modules, each with a dedicated energy storage system[79], in isolated redundant configuration for systems with "single-cord" or "single-input" loads (typical equipment with a single power supply).[80] Refer to Figure D5090-3.*

2. *Use two independent UPS systems, each with a dedicated energy storage system, serving a dual-bus distribution system for systems with predominantly "dual-cord" loads (special "fault tolerant" computer and telecommunications equipment with dual full-capacity internal power supplies feeding a common internal power bus).[81]*

3. *Use an N+1 or an N+2 redundant parallel configuration of UPS modules, each with a dedicated energy storage system, where N is the number of UPS modules required to serve the load. This configuration allows for maintenance or repair of a UPS module while the UPS system continues to support the critical load.*

D. Design grounding schemes for UPS systems in accordance with recommendations in Chapter 8 of IEEE Std 1100.

E. Design means to safely and conveniently connect a load bank to the UPS for capacity tests.

F. If UPS energy storage system (i.e. batteries or flywheel) are in a separate cabinet or rack specify an external DC fused switch with padlocking provisions so the UPS cabinet can be completely isolated and de-energized. Refer to Figures D5090-1, -2, and -3.

G. Specify UPS battery monitoring systems[82] based on the following:

1. Each UPS module shall indicate UPS run time in minutes remaining and provide an alarm output contact at 5 minutes (field adjustable) remaining. *Run time indication*

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76 An external bypass switch and external battery disconnect switch permits safe maintenance of the UPS while keeping critical systems in operation: refer to §4.3.10 in IEEE Std 446-1995.

77 A separate bypass input source increases UPS system reliability and makes it possible to maintain the UPS and upstream circuit breakers while still providing power to critical loads.

78 Refer to Chapter 6 in IEEE Std 493-1997.

79 IEC 62040-3 defines a UPS unit (or module) as a complete UPS consisting of at least one each of the following functional units: UPS inverter, UPS rectifier, and battery or other energy storage means which may operate with other UPS units to form a parallel or redundant UPS.

80 If the primary UPS module should fail, the secondary UPS module will continue to provide conditioned power to the critical load through the static switch in the Primary UPS module. The circuit breakers in the bypass switchgear can be arranged so either UPS module can support the critical load while maintenance or repairs are being performed on the other. Refer to §7.3.2.1.2 in IEEE Std 1100-1999.

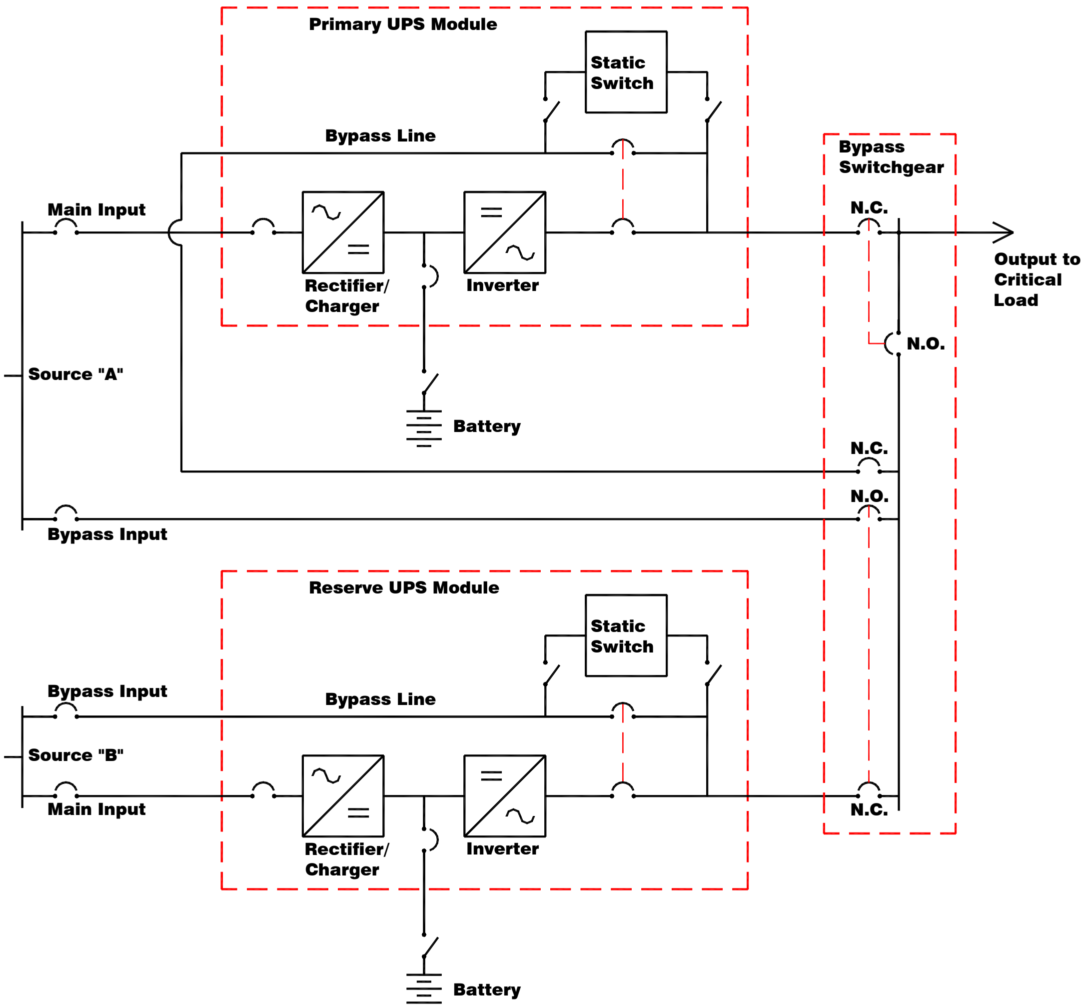
81 Either UPS system can support the critical load while maintenance or repairs are being performed on the other.

82 Since the battery is the most failure-prone sub-system of the UPS, monitoring battery condition is essential to UPS system reliability.

should be based on actual UPS load and battery discharge characteristic, not just a timer.

2. Use an NRTL-listed battery integrity monitoring system[83] that operates on a battery interconnection point basis to monitor individual cells for the following systems:
   - UPS systems over 225 kVA.
   - UPS systems with battery replacement cost over $20,000.
   - UPS systems serving Safety Class systems.

Figure D5090-3: Typical Isolated-Redundant UPS System



H. For UPS installed in information technology equipment rooms, design remote EPO interface to shut down UPS AC output and to trip remote DC circuit breaker.[84]

83 Battery monitoring improves system reliability by detecting battery problems at an early stage, before they can cause an abrupt system failure. Problems are detected by measuring the internal resistance of each cell or module in the system. The internal resistance of a cell is a reliable indicator of a battery's state of health. The only other method for testing a battery's condition is to perform a capacity test, but users are often reluctant to capacity tests their battery systems. With a suitable battery monitoring system a resistance test can be performed automatically by remote control. Refer to IEEE 1491 *Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications.*

84 Refer to section 645.11 in the NEC (2005 Edition).

I. Specify remote communications interface for UPS. UPS shall be Simple Network Management Protocol (SNMP) compatible and multi-computer interfaceable.

J. Three-phase UPS input current THD shall not exceed 10 percent.[85] *NOTE: Be cautious about excessive harmonic currents when installing multiple single-phase UPS systems in a facility!*

3.5 UPS Installation

A. Locate UPS considering security, fire separation, noise, floor loading, heat rejection, installation and replacement access, maintenance access, spare parts storage, and the following guidance:[86]

1. *UPS system 225 kVA and larger should be in a dedicated UPS room.*
2. *UPS louder than 60 dBA (measured one meter from the UPS) should not be located in any occupied space.*
3. *UPS serving Safety Class systems should be installed in a dedicated UPS room rated for design basis accident.*

B. Locate UPS battery considering floor loading, installation and replacement access, maintenance access, and the following guidance:[87]

1. *Batteries should be physically isolated from UPS electronics to prevent corrosion of the electronics.*
2. *For a UPS system over 15 kVA, provide a separate battery compartment or cabinet with batteries on slide-out trays.*
3. *For a UPS system over 100 kVA, battery should be rack mounted in dedicated battery room; refer to the* Stationary Battery Power Systems *heading in this Section for installation requirements.*
4. *Battery for a three phase UPS system serving Safety Class loads should be rack mounted in a dedicated battery room rated for design basis accident; refer to the* Stationary Battery Power Systems *heading in this Section for installation requirements*

3.6 Building Auxiliary Systems

A. Design building auxiliary systems required for proper operation of the UPS system.

B. Design UPS room HVAC system considering operating temperature, continued operation, maintenance, and the following requirements:

1. Maintain a yearly average temperature of 77F with a 50F to 100F maximum range.[88]
2. Provide 30 percent efficiency air filtration.[89]

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85 Refer to Chapter 10 in IEEE Std 519, *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*. Current total harmonic distortion (THD) at the service point is limited to 5%. It is anticipated that approximately half of the loads in a facility will be harmonic producing. Therefore significant individual harmonic producing loads, such as UPS, are limited to 10% current THD.

86 Refer to Chapter 7 in NFPA 111 (2005 Edition).

87 Refer to Chapter 5 in IEEE Std 484-1996 for vented lead-acid batteries and Chapter 5 in IEEE Std 1187 for valve-regulated lead-acid batteries.

88 100F is the maximum ambient temperature listed by most UPS manufacturers. 50F is the minimum ambient temperature in which a UPS service technician can work efficiently.

3. UPS room HVAC must continue while UPS operates on battery power to keep the ambient temperature below 100F[90]. *If the UPS is supported by a generator, the UPS room cooling can be powered by the generator.*
4. UPS room cooling must continue during HVAC system maintenance[91]—*this often necessitates a redundant HVAC system for the UPS room.*

C. Require Class C portable fire extinguisher(s) at the UPS system. Consult with the LANL Fire Protection group to determine fire extinguisher size, type, and placement.

D. Back-up engine-generator system, if used, must be selected for UPS support including an isochronous governor and a UPS compatible voltage regulator.[92] Generator must be capable of simultaneously supporting the UPS load, UPS battery charging, and UPS room cooling. *Coordinate selection with UPS manufacturer.*

E. Design emergency lighting for the UPS and battery location.[93] *Use both battery-powered emergency lights and fluorescent luminaires connected to a UPS supplied circuit.*

F. Specify Category B transient voltage surge suppression on UPS input and bypass circuit(s).[94]

3.7 UPS System Acceptance Testing and Inspection

A. Perform complete acceptance testing and inspection of completed UPS system in accordance with NFPA 111[95], IEEE Std 944[96], and IEEE Std 1100[97].

1. Provide advance notification of acceptance testing to the LANL Electrical AHJ.
2. Tests shall be performed by qualified personnel such as the UPS manufacturer's factory-trained technicians or technicians that are certified in accordance with ANSI/NETA ETT-2000, *Standard for Certification of Electrical Testing Technicians.*
3. Make a detailed record of acceptance test results on a form suitable for the purpose.
4. Provide analysis and recommendations with the acceptance test report.

B. Specify that copies of the acceptance test report and all certifications be delivered to the LANL electrical AHJ and to the Facility Manager.

89 30% filtration will provide adequate cleanliness in the UPS space. Refer to ESM Chapter 6.
90 If UPS room HVAC stops when the UPS is operating on battery power, the UPS space temperature will quickly rise and the UPS will shut down due to overtemperature.
91 If UPS room HVAC is shut down for maintenance, the UPS space temperature will quickly rise and the UPS will shut down due to overtemperature.
92 Non-linear UPS load imposes unusual conditions on high-impedance sources such as engine-generator systems.
93 Emergency lighting will facilitate troubleshooting the UPS during a power blackout.
94 Refer to 7.4.4 in NFPA 111 (2005 Edition) and 8.6.5 in IEEE Std 1100-1999.
95 Refer to 7.6 in NFPA 111 (2005 Edition).
96 Refer to Chapter 7 in IEEE Std 944-1986.
97 Refer to 7.5 in IEEE Std 1100-1999.

4.0 STATIONARY BATTERY POWER SYSTEMS

4.1 General

A. This article applies to stationary battery power systems with a stored energy capacity exceeding 1 kWh or a floating voltage that exceeds 115 volts but does not exceed 650 volts.

B. Design stationary battery power systems (battery rooms or enclosures, batteries, battery charging systems, DC distribution equipment, support systems, and auxiliary systems) as described in this heading to support loads for which the User requires uninterruptible DC power such as switchgear controls, alarm systems, inverters, and UPS systems.

1. Battery system requirements for small UPS systems with integral batteries are described under the UPS Systems heading of this Section.
2. Engine starting (cranking) battery systems are described under the Engine-Generator Systems heading of this Section.
3. Battery system requirements for fire alarm systems are described under the Fire Alarm System heading of Section D5030.

C. Design, furnish, install, and acceptance-test stationary battery power systems in conformance to the following codes and standards and this Section:

1. NFPA 70, *National Electrical Code* (NEC)
2. NFPA 70E, *Standard for Electrical Safety in the Workplace*, including all applicable fine print notes.
3. NFPA 111, *Stored Energy Emergency and Standby Power Systems*
4. IEEE Std 446, *IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications*
5. IEEE Std 450, *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications*
6. IEEE Std 484, *IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications*
7. IEEE Std 485, *IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications*
8. IEEE Std 946, IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations
9. IEEE 1184, *Guide for Batteries for Uninterruptible Power Systems*
10. IEEE Std 1187, *IEEE Recommended Practice for Installation Design and Installation of Valve-Regulated Lead-Acid Storage Batteries for Stationary Applications*
11. IEEE Std 1189, *IEEE Recommended Practice for Selection of Valve-Regulated Lead-Acid Storage Batteries for Stationary Applications*

D. Refer to Section D5000 paragraph 12.0 for additional requirements applicable to stationary battery systems classified as ML-1, ML-2, Safety Class, or Safety Significant.

4.2 Battery Power System Survivability

A. Stationary battery power systems with I_p greater than 1.0 (typically those serving Safety Class systems, Safety Significant components, life safety systems, switchgear control systems, or critical telecommunications systems) must be capable of performing the intended function during and after a design basis event.

B. Equipment for stationary battery power systems designated with I_p greater than 1.0 must be certified by the manufacturer to withstand the total lateral seismic force and seismic relative displacements specified in the IBC or ASCE 7.

1. Component manufacturer's certification shall be based on shake table testing or experience data (ie, historical data demonstrating acceptable seismic performance), or by more rigorous analysis providing for equivalent safety.
2. Required response spectra shall exceed 1.1 times the in-structure spectra determined in accordance with IBC AC156 *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems*.

C. Design support and seismic anchorage for battery power system components and associated auxiliary equipment in accordance with the IBC or ASCE 7. Refer to LANL Master Specification Section 26 0529, *Hangers and Supports for Electrical Systems* for material and installation requirements.

D. Do not locate battery power system in a building area that is subject to flooding.**Error! Bookmark not defined.**

4.3 Battery Power System Configuration

A. Select battery power system components based on 20-year life cycle cost analysis. *Consider the following factors:*

1. *Initial cost of battery power system and directly associated building floor space (e.g. battery room) and support systems (e.g. battery room ventilation, and special plumbing).*
2. *Energy costs including those of directly related building support systems.*
3. *Scheduled maintenance costs for battery power system, and directly associated building floor space and support systems.*
4. *Predicted repair and replacement costs for battery power system, and directly associated building support systems.*

B. Select the battery type using the following guidelines:

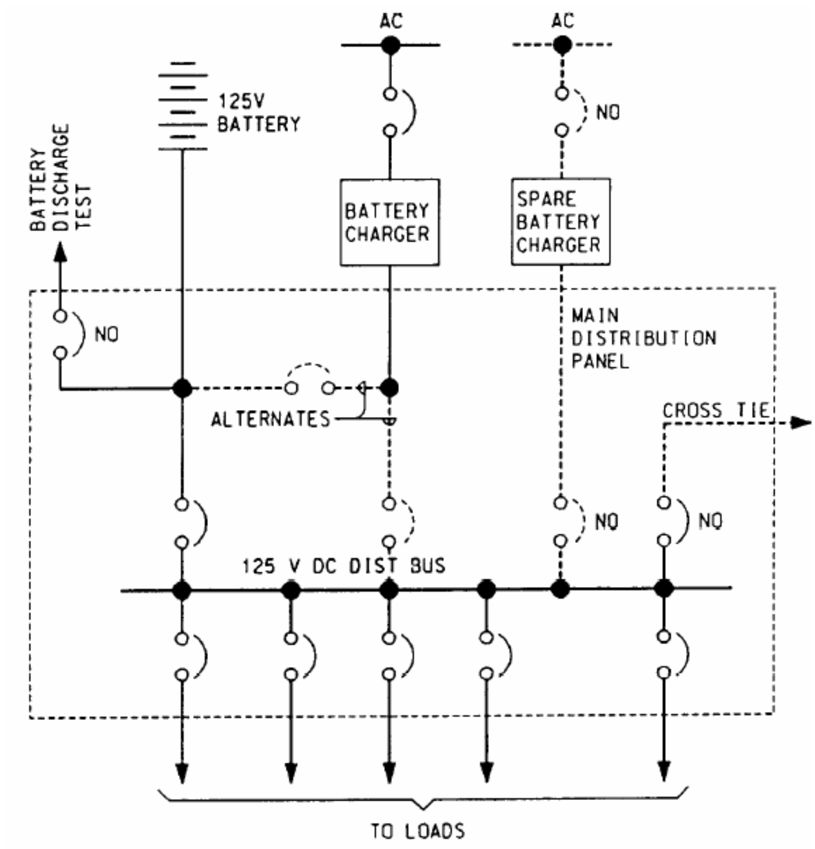
1. *Systems serving loads over 225 kVA should have vented (flooded) lead-calcium or lead-selenium cells with transparent jars and flame arrester vents.*
2. *Systems serving Safety Class loads should have vented (flooded) lead-calcium or lead-selenium batteries or cells with transparent jars and flame arrester vents or fully redundant strings of valve regulated lead acid batteries.*
3. *Valve regulated lead acid batteries may be used with non-Safety Class systems up to 225 kVA. NOTE: This type battery will need to be replaced at about 55-month intervals.*
4. *Nickel-cadmium batteries should be avoided due to hazardous waste disposal issues.*

C. Determine system loads and duty cycles for the postulated events. Size battery in accordance with IEEE 1184, IEEE Std 485, or IEEE Std 1189 (depending on the battery type) using the following factors:

1. Temperature correction factor 1.0
2. Design margin factor 1.0
3. Aging factor 1.25

D. Design battery power system with 20 percent future load growth capacity.

Figure D5090-4: Typical Switchgear Control Battery System



E. Certain critical loads such as Safety Class systems or critical telecommunications loads may require increased system reliability beyond that which can be provided by a single UPS system. Determine reliability requirements and system capabilities using analysis methods described in IEEE Std 493.[98] Provide redundant battery chargers and/or cross ties to redundant battery systems as required to meet availability and reliability requirements needed to meet User requirements. Refer to Figure D5090-4 for a 125v battery system that is typical for substation switchgear control applications; other applications will have different voltages, components and configurations.

F. Design means to safely and conveniently connect a load bank to the battery system for capacity tests. Refer to Figure D5090-4.

[98] Refer to Chapter 6 in IEEE Std 493-1997.

G. Specify battery power system with instruments or other approved display means, including remote annunciation capability, to indicate the following:[99]

1. Battery current (ammeter, charge or discharge).
2. Battery charger output current (ammeter).
3. Battery or DC bus voltage (voltmeter).
4. Battery charger output voltage (voltmeter).

H. Require individual visual indicators, a common audible annunciator, and contacts for remote alarm annunciation for the following:[100]

1. Low battery voltage.
2. High battery voltage.
3. Battery circuit breaker open.
4. Battery charger output failure.
5. High pilot cell temperature.
6. High battery current.
7. Ground fault

I. Specify a DC ground fault detection & alarm system for battery strings with nominal voltage of 115 volts or more.[100, 101]

J. Specify a battery integrity monitoring system that operates on a battery interconnection point basis for the following systems:

1. System serving load over 225 kVA.
2. System with battery replacement cost over $20,000.
3. System serving Safety Class systems.

K. Specify "battery-eliminator" type battery charging equipment that meets NEMA PE5—*Utility Type Battery Chargers* and is listed to UL 1012.[102]

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[99] Refer to Table 2 in IEEE Std 946-1992.

[100] Refer to §320.3(H) in NFPA 70E (2004 Edition).

[101] DC distribution systems are typically two-wire ungrounded battery/charger systems equipped with ground-detection/alarm circuitry including features such as annunciation in a control room, local indication, and recording. Ground detectors are incorporated in the DC systems so that if a single ground does occur, personnel are aware of the ground and can take immediate steps to clear the ground fault from the system. Failure to promptly eliminate a single ground could mask subsequent additional grounds. Multiple grounds could lead to unpredictable spurious operation of equipment, inoperable equipment, unanalyzed loads on batteries, or unanalyzed equipment failure modes that could be expected to occur during harsh environments attendant to accidents. In addition, installed ground detectors and portable ground-locating equipment themselves may create a ground on the dc system and may not maintain a minimum threshold resistance-to-ground value above which predictable system/component operation can be assured.

[102] A "battery-eliminator" type charger will allow the charger to support the DC load while the battery is disconnected for repairs, maintenance, or testing.

L. Select DC distribution system components suitable for the maximum value of charger short circuit current that will occur coincident with the maximum battery short circuit current.[103]

M. Select DC system overcurrent devices to provide selective coordination.[104]

4.4 Installation

A. Design battery installation in accordance with NFPA 70E plus IEEE Std 484, IEEE Std 1106, or IEEE Std 1187 (depending on the battery type) and the considerations described below.

B. Locate battery power system equipment as close together and as near the center of the load as practical to minimize voltage drop and to accommodate maintenance and testing activities.[105]

C. Locate batteries within a dedicated battery room, protective enclosure, or area accessible only to qualified persons. A protective enclosure can be any of the following that will adequately protect the battery power system equipment, limit the likelihood of inadvertent contact with energized parts, and limit damage to adjacent equipment from battery fumes or spray:[106]

1. A dedicated battery room.
2. An approved battery cabinet.
3. A suitable cage or a fenced area.

D. Design working spaces around battery power system equipment as required by the NEC.[107]

E. Locate battery power system components considering floor loading, installation and replacement access, maintenance access, and the following guidance:[108]

1. *For a system serving over 15 kVA load, provide a battery or cabinet with batteries on slide-out trays.*
2. *For a system serving over 100 kVA load, battery should be rack mounted in dedicated battery room; provide minimum 4 ft aisles between racks.*
3. *Battery serving Safety Class loads should be rack mounted in a dedicated battery room rated for design basis event.*
4. *Limit height of battery racks so top terminal of battery is not more than 53 inches above floor. Provide minimum 15 inches vertical clearance above battery.*
5. *Use extra flexible cable for external connections to battery terminals. Allow for 6 inches of battery rack movement during an earthquake.*

F. Require Class C portable fire extinguisher(s) in the battery room.[109] Coordinate type, size, and placement with the LANL Fire Protection Group.

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103 Refer to 7.9 in IEEE Std 946-1992 and 7.5 in NFPA 111(2005 Edition).
104 Refer to 7.5.2 in NFPA 111 (2005 Edition).
105 Refer to 4.5 in IEEE Std 946-1992.
106 Refer to Article 320 in NFPA 70E (2004 Edition).
107 Refer to 2005 NEC Section 110.26. This NEC requirement is repeated here to remind designers that working the NEC working clearances are required about batteries.
108 Refer to 7.2 in NFPA 111 (2005 Edition).
109 Refer to 4.1 in IEEE Std 484-1996.

G. Design an emergency eyewash/shower station in each battery room or within 25 feet of a rack-mounted battery.[110]

H. Design battery area HVAC system considering operating temperature, adequate ventilation, and the following requirements: [111]

1. Maintain yearly average temperature at 77 ºF, 60 ºF to 80 ºF maximum range.
2. Provide 30 percent efficiency air filtration.
3. Temperature must not vary more than 5 ºF from coolest to warmest parts of room.
4. Provide sufficient ventilation (not less than 2 air-changes per hour) to keep hydrogen concentration below 1 percent when battery is on equalizing charge; independently vent battery room exhaust to outside. *A battery room that meets the above ventilation requirements should be considered as non-hazardous; thus special electrical equipment enclosures to prevent fire or explosions should not be necessary.*[112]

I. Provide battery rooms for vented (flooded) cell batteries with appropriate additional systems such as:

1. *Acid absorption pads or pans to contain acid from a ruptured cell.*
2. *Acid resisting construction.*
3. *Hydrogen monitoring system.*
4. *Battery room sink with acid neutralizing basin.*
5. *Annunciation of ventilation system failure at a monitored location.*
6. *Spill control kit.*

J. Design adequate illumination for the battery area[113]; refer to Section D5020 of the ESM.

1. Protect luminaires from damage by guards, finishes, or isolation.
2. Locate lighting switches and receptacles outside the battery area.
3. Provide emergency illumination for the battery location.

K. Specify warning signs inside and outside the battery room or in the vicinity of a battery area as required by NFPA 70E. Refer to Section D5000 of the ESM for information regarding safety signs and to LANL Master Specification Section 26 0553, Electrical Identification for materials and installation methods.[114]

1. Electrical hazard warning sign: Use arc-flash warning label described in LANL Master Specification Section 26 0553, Identification for Electrical Systems.
2. Chemical hazard warning signs: chemical burns, explosion
3. Notice for personnel to use and wear PPE and apparel
4. Notice prohibiting access to unauthorized personnel

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[110] Refer to OSHA 1926.441(a)(6) and Article 320 in NFPA 70E (2004 Edition).
[111] Refer to 5.1 on IEEE Std 484-1996.
[112] Refer to 5.4 in IEEE Std 484-1996.
[113] Refer to Article 320 in NFPA 70E (2004 Edition).
[114] Refer to Article 320 in NFPA 70E (2004 Edition).

4.5 Battery System Acceptance Testing and Inspection

A. Specify complete acceptance testing and inspection of completed battery power system systems in accordance with NFPA 111[115] and IEEE Std 450.[116]

1. Require advance notification of acceptance testing to the LANL Electrical AHJ.
2. Tests shall be performed by qualified personnel such as the battery manufacturer's factory-trained technicians or technicians that are certified in accordance with ANSI/NETA ETT-2000, *Standard for Certification of Electrical Testing Technicians*.
3. Require a detailed record of acceptance test results on a form suitable for the purpose.
4. Require analysis and recommendations with the acceptance test report.

B. Specify that copies of the acceptance test report and all certifications be delivered to the LANL electrical AHJ and to the Facility Manager. Acceptance tests will provide baseline data for the LANL battery maintenance program.

5.0 CABLE TRAY SYSTEMS

5.1 Cable Tray Selection

A. Design and specify cable tray and accessories manufactured in accordance with the latest edition of NEMA VE1–*Metal Cable Tray Systems* or FG1–*Fiberglass Cable Tray Systems*.[117]

B. Use cable tray type suitable for the supported cables.[118]

1. *Ladder-Type Cable Tray consists of two longitudinal side rails (or the structural equivalent) connected by individual cross members or rungs. Use for large power, control, and communications cables.*
2. *Ventilated Trough-Type Cable Tray consists of two side rails (or the structural equivalent) with closely spaced supports. Use for small power, control, and communications cables.*
3. *Solid Bottom Cable Tray consists of two side rails (or the structural equivalent) connected with a corrugated or reinforced solid bottom. Use for power, control, and communications cables requiring maximum electrical or magnetic shielding.*

C. Use cable trays that have suitable strength and rigidity to provide adequate support for all contained wiring plus a 200 lb. concentrated load at mid-span.[119] For cable trays installed outdoors, add loading due to snow, ice, and wind. *The following are guidelines to suitable minimum working load categories for cable trays:*

1. *6 and 12 in. widths: 50 lbs. per linear foot plus a 200 lb. load at mid-span.*
2. *18 and 24 in. widths: 75 lbs. per linear foot plus a 200 lb. load at mid-span.*
3. *30 and 36 in. widths: 100 lbs. per linear foot plus a 200 lb. load at mid-span.*

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[115] Refer to 7.6 in NFPA 111 (2005 Edition).
[116] Refer to Chapters 5 and 6 in IEEE Std 450-1995.
[117] NEMA VE1 and FG1 are the industry standards for metal and fiberglass cable tray.
[118] Descriptions of cable tray types are from NEMA VE1. Recommended uses are from manufacturer's data.
[119] Although walking or standing on cable trays is not recommended by cable tray manufacturers and OHSA regulations, it happens.

D. Use cable trays made of corrosion-resistant material or adequately protected from corrosion that may be encountered in use; refer to manufacturer's corrosion resistance data. *Some of the commonly available materials and finishes are listed below in approximate order of increasing installed costs:*[120]

1. *Aluminum alloy 6063-T6. Use for most outdoor or indoor applications.*
2. *Carbon steel mill galvanized. Use for non-corrosive indoor applications.*
3. *Carbon steel hot dip galvanized AFTER fabrication per ASTM A123. Use for non-chemical outdoor and industrial indoor applications.*
4. *Aluminum or steel coated with 15 mils of PVC. Use in chemical environments.*
5. *Stainless steel type 304. Use in severe chemical environments.*
6. *Stainless steel type 316. Use in severe chemical environments.*
7. *Fiberglass with polyester fire-retardant resin system type FR-P. Use where electrical isolation is required or in severe chemical environments.*
8. *Fiberglass with vinyl ester fire-retardant resin type FR-VE. Use in severe chemical environments.*

5.2 Cable Tray Installation

A. Design installation of cable tray in accordance with the NEC, NEMA VE-2 – "Metal Cable Tray Installation Guidelines", and this Engineering Standards Manual.[121] Refer to Section D5000 of the ESM for additional requirements for nuclear facilities.

B. Require that sufficient space be provided and maintained above and beside cable trays to permit access for installing and maintaining cables.[122]

1. Locate cable trays not less than 12 inches below building structure, suspended mechanical equipment, piping, ductwork, and other cable trays that would impede access to the cable tray(s).
2. *Consider center hung tray supports or bracket supports to improve access to the tray for installing cables.*

C. Design cable tray supports with wall/column brackets or with threaded rods suspended from beam clamps or concrete inserts. Select beam clamps, concrete anchors, fasteners, and support rods based on the weight of the cable tray loaded to maximum cable capacity permitted by the NEC plus a 200 lb concentrated load at mid-span plus applicable snow, ice, and wind loads.

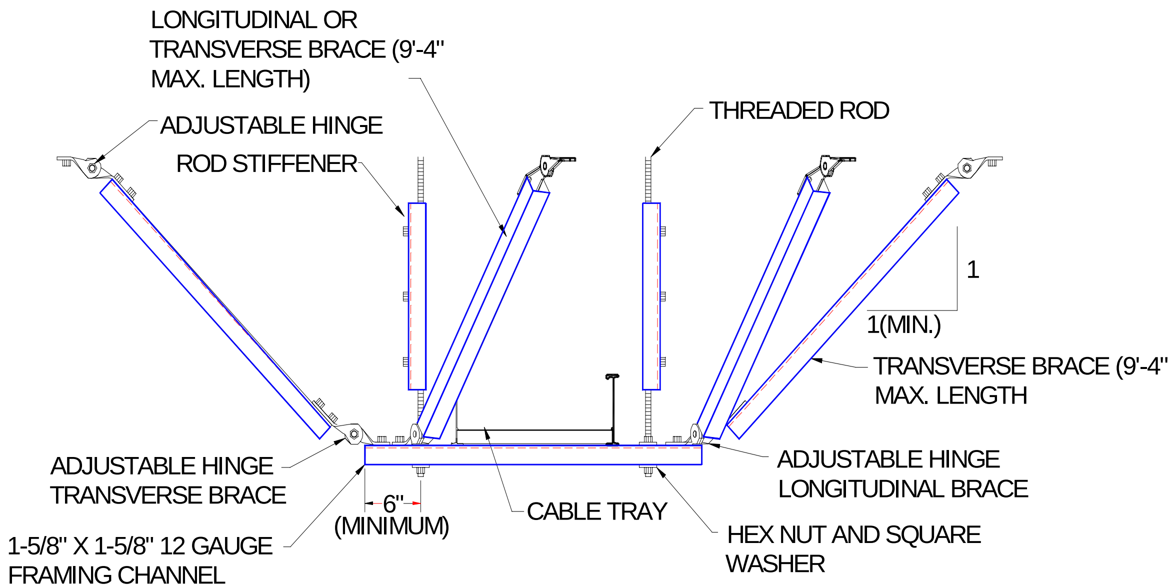
D. Design cable tray supports plus longitudinal and transverse seismic bracing as required by the International Building Code, ASCE 7, and Chapter 5 of the LANL ESM.

1. Consult a qualified structural engineer.
2. *Figure D5090-5 shows a typical cable tray seismic brace.*

E. In stacked tray installations, separate voltages; locate the lowest voltage cables in the bottom tray and succeeding higher voltage cables in ascending order of trays.[123]

[120] Corrosion resistance criteria are from manufacturer's literature.
[121] NEMA VE-2 is a practical guide for the proper installation of steel and aluminum cable trays.
[122] Requirement from NEC section 392.6(I) is repeated for emphasis.

Figure D5090-5
TYPICAL CABLE TRAY SEISMIC BRACING



F. Do not drill or punch holes in side channels of suspended cable tray other than those for splice plate bolts or grounding conductor connection fittings. *Conduits may be terminated into the side channels of continuously supported cable trays.*[124]

G. Provide covers as required to protect cables from deteriorating agents.[125]

1. Provide covers for cable trays installed outdoors.[126]
2. Provide covers for cable trays installed indoors that contain power cables where that pass under pipes containing liquids; extend covers 6 feet on each side of crossing location.

5.3 Cable Tray Grounding

A. Specify an equipment grounding conductor in cable trays sized per the NEC[127] but not smaller than 6 AWG copper. [128] Use insulated copper equipment grounding conductors in aluminum cable trays.[129]

B. Specify bonding of the equipment grounding conductor to each cable tray straight section and fitting using NRTL listed cable tray ground clamps.[130]

C. Specify bonding of the equipment grounding conductor to each enclosure or equipment item connected to, or served by, the cable tray using NRTL listed ground clamps.[131]

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123 Table tray stacking recommended practice is in section 12.5.5 in IEEE Std. 141.
124 Randomly placed holes in the side channels will reduce the beam strength of a cable tray. This is not an issue if the cable tray is continuously supported, such as on the structural floor below a raised floor system.
125 Refer to section 392.6(C) in the NEC.
126 Ultraviolet light is an outdoor deteriorating agent.
127 Refer to Table 250.122 in the NEC.
128 IEEE 1100, paragraph 8.4.12, recommends that a supplemental equipment grounding conductor be used, even if the cable tray qualifies for use as an equipment grounding conductor.
129 Refer to 4.7.2 in NEMA VE 2.
130 Refer to section D5000, which requires the use of listed fittings.

D. Require the installation of splice plates in accordance with cable tray manufacturer's instructions.

E. Specify bonding of conduits served from cable tray using NRTL listed clamps or grounding bushings.

5.4 Cable Installation

A. Use cable approved for installation in cable tray and for the location and conditions.[132]

B. Design original installations of cables in cable trays without splices.[133] *Existing cables in cable trays may be repaired using UL approved splice kits or materials.*

C. Design original installations of cables to permit future 20 percent future additions of cable.[134]

D. Specify drop-out fittings or bushings to provide a rounded surface to protect cables exiting from the bottom of cable trays.[135]

E. Do not allow pipes or tubes for water, steam, gas, drainage, or any service other than electrical in cable trays containing electric conductors or raceways.[136]

5.5 Cable Tray Labeling

A. Specify yellow warning labels with 1/2 inch black letters and the following message at visible locations 50 feet on centers on all cable trays:[137]

WARNING: DO NOT USE CABLE TRAY AS A WALKWAY, LADDER, OR SUPPORT. USE ONLY AS MECHANICAL SUPPORT FOR CABLES OR TUBING.

B. Specify red warning labels with 1/2 inch white letters and the following message at visible locations 50 feet on centers on all cable trays in environmental or return air plenums:[138]

USE ONLY PLENUM-RATED CABLES IN THIS CABLE TRAY.

C. Specify white labels with 1/2 inch black letters and the following information at visible locations 50 feet on centers on all cable trays:

1. Maximum cable tray loading depth.
2. Allowable cable load in pounds per foot based on the as-installed support span and spacing and structural support capability.

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131 Bonding of cable tray to enclosures and raceways enhances personnel safety by eliminating “touch potential”; refer to NEC Article 250.96.
132 Refer to section D5000, which requires the use of listed materials in accordance with their listing.
133 Splices should be avoided in any new installation because they are a point of reduced reliability.
134 Planning for future growth of cable tray use is recommended practice in section 12.5.5 in IEEE Std. 141-1993 and is consistent with Section D5000 of the ESM.
135 Refer to NEMA VE2, Metal Cable Tray Installation Guidelines, paragraph 4.6.2, for cable tray drop out fittings.
136 This requirement from NEC section 300.8 is repeated here for emphasis.
137 Cable tray warning label recommended in paragraph 6.3 of NEMA VE 1.
138 NEC Article 300.22(C) specifically limits the types of wiring methods that may be used within “other spaces used for environmental air.”

6.0 SIGNAL REFERENCE GRID

A. Design a signal reference grid (SRG) for computer room raised floor areas. *Refer to IEEE Std. 1100–Powering and Grounding Electrical Equipment for additional design guidance.*

B. Use one or a combination of the following systems:

1. Pre-fabricated grid of 2 inches wide by 26 gauge copper strips on 2-foot centers with all crossover connections factory welded. Bond every sixth raised floor pedestal to the SRG using 6 AWG grounding conductor.
2. Raised floor pedestal system with bolted down galvanized steel horizontal stringers.
3. 2 ft X 2 ft grid of bare No. 6 AWG conductors clamped to raised floor pedestals.

C. Specify bonding of structural steel columns, pipes, conduits, ducts, etc. passing through the SRG to the SRG using 6 AWG grounding conductor.

D. Specify bonding of computer equipment, power panels, and computer distribution units to the SRG using low impedance risers (LIR).

1. Install LIR as 2 inches wide, 26 gauge copper strips or 1 inch wide flexible braided copper straps.
2. Do not connect the LIR to the SRG conductor closest to the outside edge of the SRG.
3. Keep the LIR as short as possible.
4. If LIR exceeds 24 inches, install two parallel LIRs connected to opposite corners of the equipment. Make the second LIR 20 percent to 40 percent longer than the first.

7.0 LIGHTNING PROTECTION SYSTEMS

7.1 Criteria

A. Design a lightning protection system (LPS), including surge protection equipment, for each structure that meets any of the following criteria:[139]

1. Contains facilities for the use, processing, and storage of radioactive, explosive, and similarly hazardous materials.[140]
2. Extends more than 50 feet above adjacent structures or terrain.[141]
3. Contains equipment valued over $1 million, critical operating equipment or services considered essential to public safety.[142]
4. Is protected by an automatic sprinkler system.[143]

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[139] Criteria from DOE-STD-1066-99, Fire Protection Design Criteria.
[140] DOE G 420.1-1 requires that lighting protection be considered for buildings and structures that contain, process, and store radioactive, explosive, and similarly hazardous materials.
[141] NFPA 780 risk index increases significantly for tall structures.
[142] NFPA 780 risk index increases significantly for structures having high-value contents, critical operating equipment, or essential services.
[143] The logic is that a facility that warrants an automatic sprinkler system also warrants lightning protection.

5. A lightning risk assessment as described in the lightning risk assessment annex of NFPA 780 indicates that the calculated “expected lightning stroke frequency to the structure” (N_d) is greater than the calculated “tolerable lightning frequency to the structure” (N_c).[144]
6. Is an open shelter (e.g. bus shelter) that is not in the “zone of protection” of a nearby taller structure.[145]

B. For the lightning risk assessment described in NFPA 780 use a flash density of 8 flashes/km^2/year for all LANL facilities.[146]

C. For structures <u>not</u> used for the storage or handling of explosives, design and install the LPS in accordance with:

1. NFPA 780–*Standard for the Installation of Lightning Protection Systems,*[147] supplemented by UL 96A–*Installation Requirements for Lightning Protection Systems,* and LPI 175–*LPI Standard of Practice*,
2. LANL Master Specifications Section 26 4100 *Facility Lightning Protection,*
3. And this Section of the LANL Engineering Standards Manual.

D. For structures used for the storage or handling of explosives, meet the requirements of DOE M 440.1-1A–*Explosives Safety Manual*.

1. Design and install the LPS for explosives handling and storage facilities according to the requirements described above plus:
   - NFPA 780 Annex for Protection of Structures Housing Explosive Materials,[148]
   - MIL-HDBK 1004/6–*Lightning Protection*,[149]
   - LANL Master Specifications Section 26 4115 *Lightning Protection for Explosives Facilities*,
   - And this Section of the LANL Engineering Standards Manual.
2. The acceptable types of LPSs are mast, catenary, integral air terminal, and Faraday cage or Faraday-like shield systems. Faraday cage or Faraday-like shield systems (in conjunction with a Franklin-type system to protect the structure) are preferred for new explosives handling and storage facilities.[150] *The Faraday cage is intended to protect the interior of the structure and its contents from high electric fields and resultant arcs; the Franklin type system (NFPA 780 mast, catenary, and integral air terminal systems) is intended to protect the structure from fire, perforation, and other damage.*

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144 Refer to Annex L in NFPA 780 (2004 Edition).
145 Refer to §4.7 in NFPA 780, 2004 Edition. Structures located within a “zone of protection” are protected by the taller structure.
146 Based on flash density map from Global Atmospherics that covers a 30-mile radius centered on LANL TA-3.
147 NFPA 780 is included in the set of LANL “Work Smart Standards”.
148 Annex K to NFPA 780 is elevated to a requirement document for explosives processing and storage facilities at LANL.
149 MIL-HDBK 1004/6 addresses the design of lightning protection for explosives facilities much more comprehensively than NFPA 780.
150 Refer Chapter X in DOE M 440.1-1A “DOE Explosives Safety Manual.”

E. For open shelters design and install the LPS in accordance with:

1. NFPA 780–*Standard for the Installation of Lightning Protection Systems,* supplemented by the NFPA annex “Protection for Picnic Grounds, Playgrounds, Ball Parks, and Other Open Places,”[151]
2. LANL Master Specifications Section 26 4100, Facility Lightning Protection,
3. And this Section of the LANL Engineering Standards Manual.

F. Extend an existing LPS to any building addition if the addition is not within the existing LPS “zone of protection”. Determine the “zone of protection” using the “rolling sphere” concept described in NFPA 780.[152]

1. For structures not used for the storage or handling of explosives use a rolling sphere with a radius of 150 ft.
2. For structures used for the storage or handling of explosives use a rolling sphere with a radius of 100 ft.[153]

G. For new installations or major renovations, require that the installer furnish shop drawings showing LPS, installation details, and list of materials.

H. Use a qualified installer to design and install the LPS. Installer must have either a current LPI Master Installer certification or current UL listing (Category OWAY) for Lightning Protection Installation.[154]

7.2 Grounding System

A. For new structures design an LPS ground ring electrode (counterpoise), minimum 1/0 AWG[155] (4/0 AWG[156] for Class II systems) bare copper, at a distance of five feet from the foundation and 3 feet below grade[157]. Locate at least 6 feet from any electrical system or communications system ground electrode.[158] Backfill with a non-corrosive ground enhancement material to lower resistance to earth.[159] Design grounding electrode system to obtain the following ground resistance:

1. Structures not used for the storage or handling of explosives: 25 ohms or less
2. Explosives handling and storage facilities: 10 ohms or less.[160]

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151 Annex G in NFPA 780 (2004 Edition) establishes requirements and good practice guidelines for providing protection to personnel in open shelters. Design issues addressed include reducing step potential, reducing touch potential, and reducing sideflash to personnel.
152 Refer to §4.7.3 in NFPA 780 (2004 Edition).
153 Refer to §2.16 in DOE M440.1-1A.
154 Installer certification or listing assures national standards are met including those set forth in NFPA 780 and UL 96A. Certification places requirements on design, materials, workmanship, and inspection.
155 1/0 AWG is a close match to the outside diameter of the main conductor for Class I systems.
156 4/0 AWG is a close match to the outside diameter of the main conductor for Class II systems.
157 Ground ring should be located below the frost line, generally accepted as 36 inches at LANL.
158 Separation is required so one grounding electrode will not reduce the effectiveness of the other.
159 In dry areas and in soils with high resistivity, such as the volcanic tuff at LANL, backfill materials such as bentonite or coke breeze improve the performance of grounding electrodes. They do this through a combination of increasing the soil moisture content, decreasing the resistance of the electrode to soil interface, and increasing the effective diameter of the electrode.
160 Refer to §4.2.1 in MIL-HDBK 1004/6.

B. For existing structures verify the integrity and measure the ground resistance of the existing LPS grounding electrode.

1. Verify that the LPS grounding electrode is a separate electrode from that used for the building electrical system.
2. Design supplemental grounding electrodes to obtain an LPS ground resistance of 25 ohms or less for ordinary structures and 10 ohms for or less for explosives handling and storage facilities. *Electrolytic ground rods installed in accordance with the manufacturer's instructions may be used for such supplemental electrodes.*

C. Bond the LPS counterpoise to the main building grounding electrode bar at the service entrance.[161]

D. For open shelters, in addition to the LPS counterpoise ground ring described above, design the following supplemental grounding and bonding:

1. Design radial electrodes connected to each exterior corner of the counterpoise ground ring. Design additional radial electrodes where down conductors connect to the counterpoise ground ring between the corners. Design each radial electrode in a separate trench extending outward from the corner of the ground ring. Each radial shall be not less than 12 ft long and shall diverge at an angle not greater than 90 degrees. Radials shall be the same material and depth as the counterpoise ground ring.[162]
2. Design a down conductor at each corner of the structure.[163] Design additional down conductors so the average spacing between down conductors does not exceed 100 ft.[164] Bond down conductors to the top and bottom of the columns and to the counterpoise ground ring.[165]
3. Specify electrical insulation around columns and down conductors from the floor to 8 ft above the floor. Use material that provides not less than 600 volts electrical insulation and is resistant to impact, climatic conditions, and ultraviolet light.[166]
4. Design a grounding grid under the floor of the structure and extending to not less than 33 inches outside the perimeter of the structure.[167] Use the same material as the counterpoise ground ring. Spacing between conductors shall be not more than 3.3 ft and depth of the grid shall be no less than 6 inches and no greater than 18 inches. Interconnect grid conductors at the perimeter and at each intersection.[168] Connect ground grid to counterpoise ground ring at each corner and at additional points so average spacing between connection points is less than or equal to 30 ft.[169]

[161] Refer to §250.106 in the NEC (2005 Edition).
[162] Refer to §4.13.5 in NFPA 780 (2004 Edition).
[163] Refer to §G.1.1.2(1) in NFPA 780 (2004 Edition).
[164] Refer to §4.9.10 in NFPA 780 (2004 Edition).
[165] Refer to §4.9.13 in NFPA 780 (2004 Edition).
[166] Refer to §G.1.1.2(2) in NFPA 780 (2004 Edition).
[167] Refer to §G.1.1.2 and §G.1.1.3 in NFPA 780 (2004 Edition); extension of ground grid outside the structure is to reduce touch and step potential hazards to personnel entering, exiting or standing adjacent to the structure.
[168] Refer to §G.1.1.3(2) in NFPA 780 (2004 Edition).
[169] Refer to §G.1.1.3(3) in NFPA 780.

7.3 Installation

A. For new construction use a maximum air terminal spacing of 20 feet around the perimeter of the roof.[170] *Avoid long air terminals that overturn adhesive bases or require supplemental supports.*

B. To the maximum extent possible, locate roof conductors so they will be visible for inspection and testing.

C. Locate down conductors either concealed or exposed as permitted by NFPA 780.

1. *Avoid the use of through-roof connectors; make connections in parapet walls where possible.*
2. To facilitate verification of connections to the LPS ground, design an accessible down conductor disconnect in each down conductor except the one nearest the electrical service entrance. Disconnects for concealed down conductors may be located behind access panels or cover plates.

D. Bond metallic piping systems (water, gas, sewer, etc) entering the building to the LPS.[171]

E. Use the following LPS connection methods unless otherwise required by this Section or applicable codes:

1. Exothermic weld connections for underground or concealed connections of dissimilar materials.
2. Exothermic weld or IEEE Std. 837 compression connectors for underground or concealed connections of like materials. Do not use compression connections for rope lay lightning conductor connections or for ground rod connections.
3. Exothermic weld or bolted connections for accessible connections.

F. Prohibit painting of LPS bonds or connections.[172]

G. Locate strike termination devices as close as possible to ridge ends or edges; and the outside corners of flat or gently sloping roofs.

7.4 Surge Protection

A. Design and specify surge protection for electrical circuits entering and exiting all structures, including structures that may not have LPS on the roof.

B. Require an NRTL listed surge protection device (SPD) for each electrical service entering the structure.[173] Use SPDs that are listed per UL 1449 and are suitable for Location Category C3

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170 20-ft spacing allows use of air terminals that are shorter than 24 inches that do not require supplemental support. Refer to paragraph 4.6.2 in NFPA 780 (2004 Edition).

171 Refer to §9.4.1 and §10.4.1 in UL 96A.

172 Refer to §2.0d.3.(f) in Version 11C "IMPROVEMENTS TO THE DOE EXPLOSIVES SAFETY MANUAL" dated 4/18/02, voted and approved at the 46th DOE Explosives Safety Committee Meeting, 5/07/02. This requirement for explosives facilities is extended to all LANL facilities.

173 NFPA 780 requires surge protection on electrical service entrances.

as defined in IEEE Std. C62.41.[174] Refer Section D5010 of the ESM for service entrance SPD performance requirements.

C. Require an NRTL listed SPD for each electrical feeder, branch circuit, and control circuit extending from the structure to locations having exposure to lightning.[175] *Examples include circuits to other structures, to parking lot lighting, and to outside HVAC equipment.* Use SPDs that are listed per UL 1449 and are suitable for the application environments as defined in IEEE Std. C62.41. Use the same kind of SPDs as required for electrical services in Section D5010 of the ESM.

D. Require an NRTL listed SPD device for each fire alarm, security, and similar low-voltage circuit extending from the structure to other structures. Use SPDs that are listed per UL 497 and UL 497A and are suitable for the application environments.[176]

E. Require an SPD for each antenna cable or CCTV camera cable that enters the structure.[177] Where several such cables enter at one location, provide an enclosure with ground connection provisions for the SPDs.

F. Verify that suitable SPDs have or will be installed on each telecommunications line that enters the structure.

G. All electrical power circuits, communications circuits, shielded cables, etc. must be run underground in metal conduit for a minimum of 50 feet before they enter an explosives handling and storage facility. SPDs for power circuits, communications circuits, shielded cables, etc. must be installed at the transition to underground conduit, outside the 50-ft limit.

7.5 Acceptance Inspection

Acceptance inspection of the LPS will be by the LANL lightning protection subject matter expert (SME). Correct all deficiencies promptly.

174 Service entrance SPD ratings as recommended in Chapter 8 of IEEE Std. 1100-1999.
175 IEEE Std 1100 recommended practice is to protect power and data circuits serving exterior equipment.
176 Inadequate surge protection and grounding of alarm systems is a significant cause of maintenance and operational problems at LANL.
177 NFPA 780 requires surge protection on radio and television antenna lead-ins.